Studies on the Post-harvest Physiology and Handling of Strawberries

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EVERAL STUDIES (4, 5, 8) have shown strawberries, one of the most perishable fruit crops, have a considerably higher respiration e than such fruits as citrus, apples and peaches. As the marketing of wberries shifts from roadside and local markets to large retail outlets urban areas, the time between harvesting and final sale increases. More a on the post-harvest physiology and behavior of strawberries is re- red in order to devise better methods for maintaining commodity lity and reducing losses in marketing channels. With the exception of dies in California (6, 7) relatively little work has been done on straw- ry fruit physiology in the last twenty years, and it was felt that data e needed on varieties now produced in the eastern United States, in- ding West Virginia. With the development of newer methods, fruit piration can be measured more accurately and under more physiologi- conditions than was possible in most of the earlier studies.

thods

Most of the samples of fruit were obtained from the University Farm Morgantown. Fruits were obtained from plants grown by the matted method. Fruit from a commercial planting located 60 miles from the ratory was used in some of the temperature management studies. roximately two hours were required to transport this fruit to the lab- ory.

After arrival at the laboratory, the fruit was carefully examined and led to remove misshapened and diseased fruits and to eliminate fruits xtreme sizes. When maturity, or stage development, was to be studied ts were usually graded into four categories, based on the proportion e fruit surface colored red —0-25%, 26-50%, 51-75% and 76-100%. The category represents commercial ripeness. Weighed samples of the were placed in glass jars which were used as respiration chambers. se were supplied with air from flowboards similar to those originally ribed by Claypool and Kiefer (3), which provide a known constant of airflow. The flow rate depended on the method of carbon dioxide ysis, but was always great enough to maintain a carbon dioxide con- ration of less than 0.5 per cent.

At the conslusion of respiration and management experiments, fru
were sorted and classified as marketable and non-marketable. To ma
tain uniformity between experiments, this operation was performed
one worker. Fruits which showed fungal growth, excessive softness,
cessive darkening of bruised areas, shriveling, or loss of color from
calyx were classified as unmarketable.

Respiration rates were determined daily as carbon dioxide prod
tion. The carbon dioxide concentration in the air stream leaving the
piration jar was determined either by gas-liquid partition chromat
raphy (silica gel column and thermal conductivity detector) or by inf
red analysis (LIRA-cell) and respiration rates were calculated as
CO_2/kg/hr.

Results

The relationship between temperature and the rate of strawb
fruit respiration is shown in Figure 1, which is typical for many exp
ments conducted over several years. At 2° and 7° C the rate is nearly c
stant for about ten days, perhaps showing a slight increase during
last three days of the experiment. Increasing the temperature from 7
12° C about doubled the respiration rate, which remained essentially c
stant for four days. After that time decay and breakdown began,
there was a sharp rise in the respiration rate. Respiration measurem
were continued until the eleventh day after harvest even though it
obvious that essentially all of the fruit had become unmarketable by
end of the sixth day. During the period of decay the respiration
tended to increase, but was erratic. At 20° C the respiration rate was
five times higher than at 2° C and increased rapidly. After five c
breakdown and infection by fungi were extensive and the respira
measurements were terminated. Other samples held for more than t
days at 20° C sometimes showed a decline in CO_2 production, coinci
with visual indications of breakdown.

The respiration of fruits apparently at the same stage of ripen
not constant, but varies between samples picked at different times. T
1 shows rate of CO_2 production for several samples. Obviously the
considerable variation between samples. It is quite likely that this v
tion is related to environmental conditions before and at harvest, bu
detailed data were collected on this relationship. It also must be po
out that the sage of development was estimated visually by arbi
criteria, and different lots of fruit probably were very different pl
logically. The respiration data clearly indicated these differences.

From these respiratory data it is possible to obtain the respir
quotient (Q) for strawberry carbon dioxide production. It must b

TABLE 1

...iration Rates for Various Samples of Strawberries Harvested ...n 75% Red or Pink (Commercially Ripe). CO_2 Production on First Day after Harvest.

...arvest date	Temperature			
	3° C	7° C	12° C	20° C
	mg CO_2/kg/hr.			
...64	33.4	25.3	55.3	83.3
...64	11.3	11.1	41.2	87.6
...65	17.3	24.3	42.8	84.4
...66	22.2	..	..	171.8
...66	60.1	..	..	198.8
...66	25.0	..	..	169.0

...d that this is variable and changes with time after harvest. Referr... Figure 1, the Q_{10} appears to be three on the first day after harvest ...he range 2-12° and nearly three over the range of 7-12° C. The ratio ... rates at 20° C to those at 2° is 5.8 on the first day after harvest and ...ses to 9.2 on the third day. This change is ascribable to the rapid ...se in the rate of CO_2 production at 20° C. The ratios between the ...t 12° and 2° C changes less dramatically from 3.0 on the first and ...days to 5.2 on the sixth day. Q_{10} values have been found to range ...2.0 to 4.0.

...ATIONSHIP BETWEEN STAGE OF DEVELOPMENT ...AND RATE OF RESPIRATION

...rawberries will continue to develop color after harvest (1, 9), and ...been suggested that the storage and shelf life of strawberries might ...ended by harvesting them at an earlier stage of color development ... commonly done at present. The respiration of strawberries har... at four stages of development, as determined by the proportion of ...face colored pink or red, was followed. Data from a few experi... are shown in Table 2.

... some experiments, such as the fruit harvested on 6/2/65, fruit ...e least and most amount of surface color had lower respiration ...an fruit with intermediate amounts of color. This was not always ..., owever, as is shown for two other harvests (6/4/65) and 5/29/64).

...om Figure 2 it appears that the rate of respiration increases as the ... ecomes redder up to the stage of commercial "ripeness," after ... the rate decreases. The less colored fruit (Classes 1-3) showed a ...ly onsistent increase in respiration over a six-day period at 12° C. The

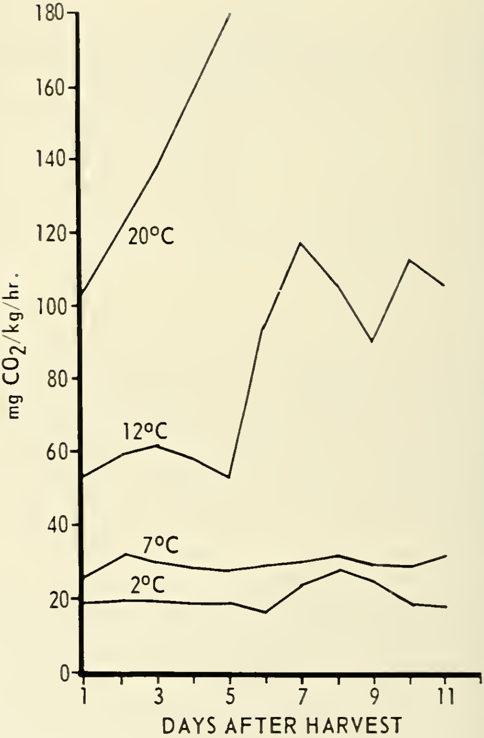
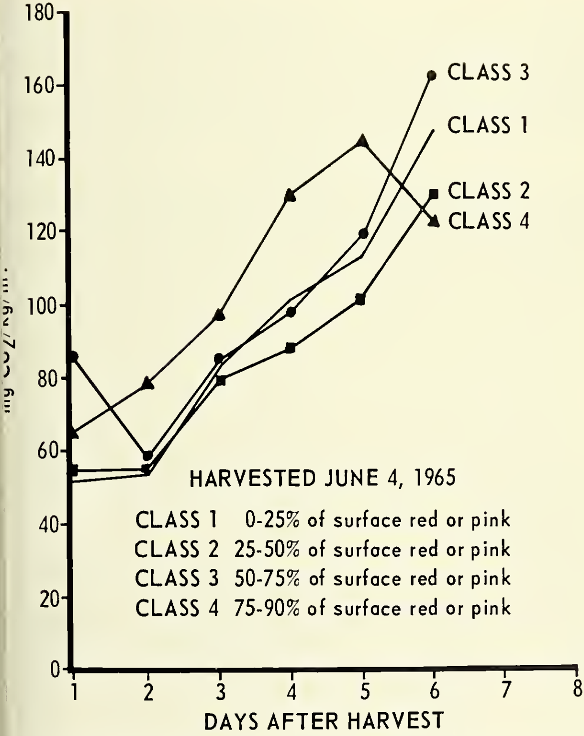


FIGURE 1. Respiration rate of ripe (color 4) strawberries at temperatures.

rates of classes 1-3 were very similar during the last four days. The piration of riper fruit (Class 4), however, increased for some five and then declined. Fruits harvested when incompletely colored were firm and sound after eight days at 12° C, while the fruit which was vested when commercially ripe had become deep red in color, du finish, very soft, and showed fungal contamination and breakdown.

Although fruits harvested with 50-75 per cent red color ha slightly higher rate of respiration than more highly colored fruits, it pears that they can be kept in storage for a longer period of time



[FIG]URE 2. Rate of respiration of strawberry fruits after harvest at four [st]ages of development.

TABLE 2

[C]arbon Dioxide Production 24 Hours after Harvest at 12°.

[H]arvest date	Maturity[1]			
	1	2	3	4
	mg CO_2/kg/hr.			
/29/64	71.3	55.9	45.9	83.3
/[illegible]/65	27.8	62.5	54.3	42.4
/4/65	52.5	55.8	56.7	78.3

[1] [C]lass 1, 0-25% red; Class 2, 26-50% red; Class 3, 51-75% red; Class 4, 76-100% [re]d.

determine if the quality of fruit which colored after harvest was differ from fruit harvested at the customary stage of development, solul solids and pH of juice were determined (Table 3 and 3A). In one expe ment, fruits in Classes 2, 3, and 4 were harvested on the same date a held for eight days at 2° C. At the end of that period, 90 per cent of the fruits were still sound and had sufficient color for marketing.

TABLE 3

Percentage Soluble Solids and pH of Fruits Harvested at Differe Stages of Development. Data Taken after 8 Days Storage at 2°

Color class at harvest	pH	% Soluble solids
	Midway	
2	3.35	5.08
3	3.42	5.19
4	3.58	5.47
	Surecrop	
2	3.27	5.52
3	3.38	5.99
4	3.45	6.32

[1]Soluble solids at harvest in fruit harvested ripe were 5.21% for Midway 6.05% for Surecrop.

TABLE 3A

Percentage Soluble Solids of Fruits Harvested at Different Sta of Development.

Color class at harvest	Initial soluble solids	Soluble solids after storage at 22 until fully red	% Soluble sol after storage 2 until fully
2	6.25	5.77	6.59
3	6.66	6.75	6.64
4	6.60	6.73	

In another experiment soluble solids were determined in three clas of fruit before and after storage until 100 per cent colored.

These data suggest that there are small differences in soluble sol and pH between fruits harvested at different stages of color developme At lower temperatures, earlier harvested fruits failed to develop levels soluble solids equal to fruits fully colored when harvested but the diff ences were small. The soluble solid content of Class 3 and Class 4 fru stayed constant or increased slightly when stored at room temperat (22 C) while the soluble solids of Class 2 fruits decreased under sim holding conditions.

EMPERATURE MANAGEMENT

Studies by Maxie *et al.* have shown that the interval between harvest the reduction in fruit temperature is critical in maintaining the qual- f California strawberries. Since different varieties of strawberries are in California and the eastern United States, it seemed advisable to estigate this aspect of temperature management.

Fruit was collected as it was brought to the field assembly point by al pickers; flats of fruit that had been harvested within the same interval were obtained. After the fruit arrived at the laboratory, ts of fruit from the trays were distributed into groups for treatment. procedure was used to at least partially reduce picker variability. At n intervals after harvests, lots of fruit were placed in a laboratory d-air cooler which operated at a static head of 0.5″ water and 4 /pound of fruit. With an ambient temperature of 3° C, fruit tem- ure was reduced from 22° C to less than 6° C in two hours. After this the fruit was stored at 2° C until evaluated or transferred to 20° C simulated shelf life.

Table 4 shows data from one of several experiments performed in 6 and 1965 with the Surecrop variety. The quality of the fruit, when ated after six days storage at 2° C and one day at 20° C was not ed by the interval from harvest to cooling. In these experiments the al was only extended to nine hours because it was thought that in cases the fruit could be delivered to a cooling facility within that

. subsequent experiment showed that in some cases the time from st to cooling may affect fruit quality. Table 5 shows that the quality Secrop berries evaluated after six days at 2° C was not affected by lay in cooling. This is in agreement with the experiment discussed usly; however, the Midway variety showed differences in quality d to the harvest-to-cooling interval, and those differences were even pronounced after a simulated shelf trial of three days.

TABLE 4
ect of Cooling Delay on Quality of Surecrop Strawberry Fruits.[2]

al from harvest nning of cooling	Per cent marketable by weight after	
	6 days at 2°	1 day at 20°
3 hours	89.2	92.3[1]
5 hours	95.7	94.3
7 hours	92.8	95.5
9 hours	98.6	96.9

[1] uit unmarketable at first evaluation discarded.
[2] uit maintained at 20° continuously after harvest was unmarketable two days rvest.

TABLE 5

Effect of Cooling Delay on Quolity of Surecrop and Midway Strawberries.

Interval from harvest to beginning of cooling (hrs.)	Per cent marketable by weight after	
	4 days at 2°	3 days at
	Surecrop	
1	91.3	82.0[1]
3	93.9	78.8
4	91.7	81.9
5	92.8	90.9
6	95.3	89.8
	Midway	
1	92.5	75.8
3	86.3	83.2
4	90.2	76.1
5	83.7	69.7
6	69.4	67.9

[1]Fruit unmarketable at first evaluation discarded.

The data in Table 6 also suggest that early field heat removal is portant in maintaining strawberry quality. In that test cooling was begun until 7-13 hours after harvest, and after 1 day at 3° C and 1-1½ d at 20° C, 70 per cent or less of the fruit could be classified as marketa Earlier cooling times were not used in this test, but similar tests c ducted a few days earlier with fruit from the same planting showe much higher percentage of marketable fruit.

It seemed important to determine how subjecting strawberry frui different temperatures would affect quality. For these studies exp mental lots were assembled as described for the delayed cooling stud One lot was maintained continuously at room temperature (20° C); ot lots were alternated between 3° C and 20° C. The total holding time 72 hours.

An examination of the data in Table 6 suggests that successively posing strawberry fruits to relatively low and high temperatures does affect quality adversely; rather, the total hours at a given temperatur the principal factor controlling fruit quality after harvest. Treatment Table 6 was subjected to one more cooling and heating cycle than Tr ment 3, but since the fruit in Treatment 4 was at 3° C longer than fruit in Treatment 3, there was more marketable fruit in Treatment the end of the experimental holding period. Holding at 3° C for 50 cent of the period at least doubled the percentage of marketable fruit c fruit held continuously at 20° C.

TABLE 6

ffect of Alternating Temperatures after Harvest on Strawberry Fruit Quality.

		Time at 3° and 20° C[1]							Per cent marketable by weight	
ol hours t 3°		0	12	24	36	48	60	72	Midway	Surecrop
0	20°								42.3	25.2
	3°									
60	20°								86.0	85.8
	3°									
24	20°								63.9	67.4
	3°									
36	20°								84.0	83.7
	3°									

Bars indicate time interval fruit was held at 3° C or 20° C.

The influence of alternate warming and cooling was also studied by o paring the respiration of precooled with non-precooled fruits. Uni- or samples were cooled 2-5 hours after harvest in a laboratory forced- ir ooler and then distributed into respiration chambers. Comparable ar les were held at room temperature and placed in respiration cham- er at the same time as the precooled fruit. The first respiration rate ne urements were made about eleven hours after harvest. Respiration at are tabulated in Table 7.

TABLE 7

Effect of Precooling on Respiration Rate of Strawberries. (Surecrop Variety)

itial t tment	Holding temperature	Hours after harvest				
		6	24	48	72	96
		Respiration rate - $mgCO_2/kg/hr.$				
on recooled	3°	38.3	8.9	17.6	14.8	13.1
'rec led	3°	23.2	12.9	17.1	16.4	19.4
on recooled	25°	104.8	55.6	123.1		
're- oled	25°	52.7	58.9	122.6		

The effect of precooling on respiration at the time of the first me surement (6 hours) is evident. The non-precooled fruit at 3° C was co ing slowly and still had a higher respiration rate than the precooled fr at the same temperature. On the other hand, the effect of precooling respiration of fruit held at 25° C was evident for several hours. Within hours, however, the effect of precooling on respiration was dissipated. the time of the second measurement, the rates of the precooled and no precooled fruit were essentially identical. When the samples held at 25 were examined three days after harvest, the precooled and non-precool treatments contained approximately equal amounts of marketable fr (precooled, 79.1 per cent vs. non-precooled, 76.5 per cent). These d would suggest that short-term temperature changes have no apprecial effect on fruit respiration or quality.

METHOD OF PRECOOLING

Based on the relationship between temperature and respiration ra it would be anticipated that rapid reduction of fruit temperature shou result in higher fruit quality. The two methods of precooling (rapid duction of fruit temperature) that appear to be applicable to strawberr are forced-air cooling and hydrocooling. The possible effect on fr quality is one of the factors that should be considered in the selection a precooling method.

Twenty-four quarts of Surecrop strawberries were divided into th groups. One group was cooled to less than 5° C in the laboratory forc air cooler. This cooling required approximately two hours. The sec group was cooled by showering with water chilled to 2° C by a small c stant temperature water bath equipped with mechanical refrigerati Each quart of fruit was cooled individually. Twelve to fourteen minu were required to reduce fruit temperature to less than 5° C. Each qu was transferred to a refrigerated room as soon as cooling was complet The third group was held continuously at 25° C. After three days fr were classified as marketable or unmarketable. All of the fruit was held additional three days at 25° C and again evaluated. The results of th evaluations are shown in Table 8.

The method of cooling had no effect on quality of fruit after the storage periods. There was no indication decay organisms were tr ferred between containers in the hydrocooler. It is likely that the quan of fruit involved in this experiment was too small to have made dispe of decay organisms a problem. It was noted that the fresh weight of hydrocooled berries had not changed after three days in storage w that of the forced-air cooled berries had decreased by 3.3 per cent their original weight). Since there was no obvious differences in

TABLE 8

Effect of Cooling Method on Strowberry Fruit Quality. (Surecrop Variety)

Treatment	Per cent marketable fruit Days after harvest	
	3	6
Forced-air cooled	94.5	65.3
Hydrocooled	94.2	67.5
Non-cooled	24.7	13.4

pearance of the two groups of fruit, this weight change difference did appear to be important.

cussion

When a fruit such as the strawberry is harvested it is removed from urce of water and organic compounds. As respiration continues, carydrates and perhaps other constituents will be degraded. Extensive tization and breakdown of tissue components lead to changes in struc- and appearance of the fruit. Respiration is not the only complex of esses which occurs in harvested fruits that result in quality changes, it can be used as a convenient index of metabolism because respira- is relatively simple to measure.

Respiration, as defined by carbon dioxide production, is highly de-lent on temperature. Temperature increments of 10° C have been d to raise the respiration rates of strawberries as much as fourfold. would indicate that a primary objective of any management or hand- system for strawberries must be protection from high temperatures. le this is true for any perishable commodity, it is particularly critical trawberries because of their comparatively high rate of respiration. w temperatures strawberries may have a relatively constant respira- rate for ten to twelve days, but at common outside early-summer eratures—around 25° C—the respiratory rate rises rapidly after har- (Figure 1). Since the rise is much less and develops more slowly at eratures of 12° C or so, relatively simple temperature management ms would be expected to materially retard strawberry fruit deteriora- The work reported in these studies shows that over 60 per cent of stored at 20° C became unmarketable after three days while at 2° C were no significant changes in quality for ten days or even longer.

Because of the effect of temperature on fruit respiration and deteri-on, it would seem logical to maintain low fruit temperatures when- possible. Temperature alternations do not accelerate strawberry

fruit breakdown. Rather, data reported here and by Maxie *et al.* (6, 7 demonstrate that fruit quality is proportional to temperature: that is, th quantity of marketable fruit after a given holding period depends up the time the fruit is held at a relatively low temperature.

Fruits are sometimes divided into two groups (2). Climacteric frui show a definite rise in carbon dioxide production during the latter stag of development. This rise is usually associated with color changes, ac cumulation of certain compounds such as sugars, and perhaps softenin Other fruits, termed non-climacteric, generally show a decreasing rate carbon dioxide production as they approach "ripeness" or the edible stat usually characterized by being fully colored. Strawberries are consider to belong to the non-climacteric group. The data from these studies ten to confirm this concept. In some experiments samples containing fru with intermediate coloring (maturity Classes 2 and 3) did show a high rate of carbon dioxide production than samples with Class 1 and 4 fruit however, this pattern was not consistent. The general pattern seems to b an increasing rate of CO_2 production with increasing maturity. Maturit Class 4 fruits at higher temperatures (20° C) show a very rapid rise du ing the first 48-72 hours after harvest followed by a decline of around per cent. At 12° C the rise is slower, lasting us to 120 hours. Less matu fruit show a rather gradual increase for 6-8 days with perhaps a slight de cline after that time. Climacteric patterns may be difficult to demonstra in massed samples where fruits are matched on the basis of visual chara teristics. Several measurements with single fruits through the period color development did not show a consistent peak of carbon dioxide pr duction. Another characteristic of the climacteric rise in carbon dioxi production is an increased evolution of ethylene. In these studies many tempts were made to detect ethylene, but only trace amounts were ev found, and then only samples of over-ripe fruits showing fungal infectio The available evidence supports the conclusion that the strawberry is non-climacteric fruit.

These studies would suggest that it is feasible to harvest strawberr at an earlier stage of development than is the present practice. Fruits maturity Classes 3 and 4 do not differ greatly in soluble solids and pH two characteristics that are important in determining fruit quality. Und unfavorable transportation and marketing conditions that would inclu prolonged holding at prevailing temperatures, harvesting when the fr is 60-70 per cent colored may extend the total marketing opportunity two to three days.

Maxie *et al.* in their work with California strawberries have empl sized the rapid decline in quality as the time between harvest and r moval of field heat is extended. Their data indicate that normally fr

ld be placed in precoolers within three hours after picking. The fits of prompt cooling were apparent even when quality evaluations made as soon as 72 hours after harvest. The data reported in this tin would suggest that rapid handling is not so critical in West Vir-. There were no consistent differences in quality of Surecrop straw-es correlated with harvesting-to-cooling intervals of two to ten hours. e is some evidence that the interval may be more critical with the vay variety, which appears to deteriorate more rapidly than Sure-. The differences between the findings reported here and those from ornia can be attributed in part to varietal differences. Also, the pre-ng temperatures in California may have been higher than they were this work was done in West Virginia. The present information ly indicates that early refrigeration is beneficial at least in maintain-trawberry quality.

Holding strawberries alternately at low and high temperatures does ffect quality adversely. Since the data from these studies and else-e show that quality decreases in proportion to the time at high tem-ures, the use of refrigerated holding and transportation facilities d be used wherever available.

ature Cited

istin, M. E., V. G. Shutak and E. P. Christopher. 1960. Color changes in har-sted strawberry fruits. Proc. Amer. Soc. Hort. Sci. 75:382-386.

ale, J. 1960. Respiration of fruits—Handbuch der Pflanzenphysiologie 12(2): 6-92.

aypool, L. L. and R. M. Kiefer. 1942. A colorimetric method for CO_2 determi-tion in respiration studies. Proc. Amer. Soc. Hort. Sci. 40:177-186.

ller, M. H., P. L. Harding, J. M. Lutz, and D. H. Rose. 1931. The respiration some fruits in relation to temperature. Proc. Amer. Soc. Hort. Sci. 28:583-589.

ller, M. H., P. L. Harding and D. H. Rose. 1932. The interrelation of firmness, weight, and respiration in strawberries. Proc. Amer. Soc. Hort. Sci. 29:330-4.

ixie, E. C., F. G. Mitchell and A. Greathead. 1959. Quality study on straw-rries. Calif. Agr. 13(1):6, 15.

ixie, E. C., F. G. Mitchell and A. Greathead. 1959. Studies on strawberry ality. Calif. Agr. 13(2):11, 16.

erholser, E. L., M. B. Hardy, H. D. Lochlin. 1931. Respiration studies of awberries. Plant Physiol. 6:549-557.

ith, W. L., Jr., and P. H. Heinze. 1958. Effect of color development on quality post-harvest ripened strawberries. Proc. Amer. Soc. Hort. Sci. 72:207-211.